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MESSAGE-AUTHENTICATED ENCRYPTION APPARATUS OR DECRYPTION APPARATUS FOR COMMON-KEY CIPHER

INCORPORATION BY REFERENCE

This application claims priority based on a Japanese patent application, No. 2003-157444 filed on Jun 3, 2003, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to technologies for ensuring the security of secret information.

In the conventional cryptographic processing apparatuses, block ciphers and stream ciphers whose object is to keep data confidential had been proposed. Also, starting with AES (: Advanced Encryption Standard), various types of algorithms have been proposed as the block ciphers.

In the block ciphers, the security and properties of the entire cryptographic processing are discussed based on block-cipher operation modes such as ECB, CBC, CFB, OFB, and counter modes. Up to the present time, however, only an iaPCBC mode has been known as a mode of being capable of simultaneously performing an encryption processing and a forgery detection. The remaining modes find it impossible to perform the forgery detection by their own. The iaPCBC mode has been addressed in a document "Lecture Notes in

Computer Science, Vol. 1796", V. Gligor, P. Donescu, Springer-Verlag, pp. 153-171, (2000) (hereinafter document 1)

The iaPCBC mode, which is the mode of using the block cipher, finds it impossible to perform such processings as a parallel processing and an in-advance computation in the above-described encryption processing. Accordingly, it had been difficult to implement the iaPCBC mode into an environment where a high-speed processing is requested.

In contrast thereto, there has been proposed a method of generating a forgery-detection-purpose cryptology-based checksum called "Message Authentication Code" (which, hereinafter, will be referred to as "MAC"). According to this method, in the encryption processing by the above-described block-cipher operation modes as well, the MAC generation processing is implemented as required at the same time and as a totally independent mechanism. This has allowed the simultaneous execution of the encryption processing and the forgery detection. In this case, however, the following points become necessary: Namely, totally independent cryptology-based keys need to be shared two times, i.e., the key for the encryption and the key for the message authentication need to be shared. Moreover, data to be encrypted needs to be subjected to the two-time processings, i.e., the encryption processing and the MAC generation processing. These necessary points have resulted in an apprehension that the system becomes complicated, or the system becomes unsuitable for the processing of long data, or the like. Furthermore, processing speeds by the block ciphers are lower as compared with present-day communications speeds. Consequently, it has been difficult to apply these combination technologies of the block ciphers and MAC to utilizations where the high-speed processing such as a gigabit or terabit processing is requested.

Also, it had been known that the combination of MAC and light processings makes it possible to implement operation modes. The stream ciphers, which use these operation modes as their modes, allow the simultaneous execution of the encryption processing and the forgery detection. In addition thereto, processings by the stream ciphers are high-speed ones which are at a rate of two to twenty times higher as compared with the processings by the above-described block ciphers. Similarly with the combinations of the block ciphers and MAC, however, whatever MAC generation method requires pseudo random numbers whose length is two times longer than that of a message. This has resulted in a situation that it takes a time to generate the necessary pseudo random numbers, or the two-time processings need to be performed for a single message, or the like.

Considering the MAC generation methods in more detail, mechanisms and a computation amount, which become necessary for the original stream ciphers in an attendant manner, are exceedingly large in number and amount, respectively. For example, in such MAC generation methods as UMAC, a secure Hash function becomes necessary which guarantees a one-way property without a collision in cryptology terms. Accordingly, the use as the stream ciphers requires the further implementation of this Hash function into a pseudo random-number generator. UMAC has been addressed in a document "UMAC: Fast and Secure Message Authentication", Black, Halevi, Krawczyk, Krovetz, Rogaway, Advances in Cryptology, -CRYPTO' 99, Lecture Notes in Computer Science, Vol. 1666, Springer-Verlag, (1999) (hereinafter document 2)

SUMMARY OF THE INVENTION

Most of the conventional cryptographic technologies, at the time of a decryption, have found it impossible to perform the message authentication by their own. Namely, when performing the message authentication, most of the technologies have required the following additional conditions: The necessity for sharing the different two keys, the necessity for the random numbers whose length is two times longer than that of a message, the independent processings, the additional implementation of another cryptology-based element function, and the like.

The problems concerning the processing-speed aspect are as follows: In the block-cipher operation modes known so far, there exists no possibility of implementing the degree of parallelism, the in-advance computation, and the like. This gives rise to the problem that the operation modes are unsuitable for a highly parallel processing and a high-speed processing. Moreover, in the stream-cipher operation modes known so far, the operation amount and the necessary random numbers are large in amount and number, respectively. For this reason, the processing speeds in the software implementations are of basically the same order as the ones by the block ciphers. This gives rise to a problem that an even higher-speed processing is requested.

The present invention provides an efficient, provable and secure cryptographic method. More particularly, it provides a message-authenticated cryptographic method and its apparatus that allow a message authenticity simultaneously with a decryption, and that are provable about the security in the sense of a data confidentiality and the data authenticity.

The present invention provides a common-key cipher method and its apparatus that possess advantages of an in-advance computation and a parallel processing while making the best possible use of the high-speed processing performance of a pseudo random-number generator.

The present invention provides a cryptographic method and its apparatus that not only allow a processing which is higher than the conventional block ciphers, but also allow a processing which can be implemented on a single path and is exceedingly effective in software.

The present invention provides a stream-cipher method and its apparatus that can be implemented using a small program.

The present invention, in its one mode, generates random numbers so as to perform an encryption processing and an authentication processing, thereby accomplishing an in-advance computation and a parallel computation. Also, the encryption processing and the authentication processing are performed, using the generated random numbers whose length is shorter than 2N with reference to the message length N.

Concretely, the random numbers are generated using the pseudo random-number generator, and the generated random numbers are divided on each block basis. Also, a plaintext is divided on each block basis as well. Next, the exclusive-OR logical sum of each random-number block and each plaintext block is figured out, thereby acquiring each ciphertext block. Moreover, the hash function NH addressed in the document 2 performs a key-accompanying input of the random-number blocks, thereby generating the message authentication code of the generated ciphertext. Here, the random-number generation is executable by the in-advance computation, and the ciphertext-block generating operation is executable by the parallel processing, and processing the hash function NH is also executable by the parallel processing. This condition allows the implementation of the high-speed computations.

According to the present invention, when implementing the message-authentication-equipped cryptographic method by the software programs, it becomes possible to accomplish the even higher speeding-up of the processing speed.

These and other benefits are described throughout the present specification. A further understanding of the nature and advantages of the invention may be realized by reference to the remaining portions of the specification and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates the system configuration diagram of each embodiment.

FIG. 2 illustrates the flow diagram of the plaintext-preparation subroutine.

FIG. 3 illustrates the flow diagram of the random-number generation subroutine.

FIG. 4 illustrates the flow diagram of the encryption subroutine.

FIG. 5 illustrates the flow diagram of the decryption-processing program in FIG. 1.

FIG. 6 illustrates the flow diagram of the ciphertext-preparation subroutine.

FIG. 7 illustrates the flow diagram of the decryption subroutine.

FIG. 8 illustrates the flow diagram of the plaintext cut-out subroutine.

FIG. 9 illustrates the diagram of the encryption processing by the data blocks.

FIG. 10 illustrates the diagram of the decryption processing by the data blocks.

FIG. 11 illustrates the flow diagram of the hash function NH.

FIG. 12 illustrates the flow diagram of the random-number generation 2 subroutine in the second embodiment.

FIG. 13 illustrates the flow diagram of the encryption 2 subroutine in the second embodiment.

FIG. 14 illustrates the flow diagram of the decryption-processing program in the second embodiment.

FIG. 15 illustrates the diagram of the encryption processing in the second embodiment by the data blocks.

FIG. 16 illustrates the diagram of the decryption processing in the second embodiment by the data blocks.

FIG. 17 illustrates a conceptual diagram of the random-number sharing method in the encryption processing and the authentication processing in the first embodiment.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Hereinafter, referring to the drawings, the explanation will be given below concerning a first embodiment of the present invention. Incidentally, an exclusive-OR logical sum on each bit basis is denoted by EOR in the following explanation, and, in the respective drawings, this logical sum is denoted by a notation resulting from surrounding a plus notation with a circle. (First Embodiment) FIG. 1 illustrates a system configuration which includes a computer A 1002 and a computer B 1003 connected to each other via a network 1001, and the object of which is to perform cryptographic communications from the computer A 1002 to the computer B 1003. The computer A 1002 includes therein an operation apparatus (which, hereinafter, will be referred to as "CPU") 1004, a storage apparatus (which, hereinafter, will be referred to as "RAM", and it is all right whether this apparatus is of volatile property or non-volatile property) 1005, and a network interface 1006. A display 1007 and a keyboard 1008 for a user to operate the computer A 1002 are connected thereto at the outside thereof. Information stored in the RAM 1005 are as follows: An encryption processing program PROG1_1009, a random-number generation processing program PROG2_1010, a secret key K 1011, i.e., secret information shared only between the computer A 1002 and the computer B 1003, an initial vector I 1013, i.e., data shared between the computer A 1002 and the computer B 1003, and a message M 1014 that the user wishes to encrypt and transmit to the computer B 1003. The computer B 1003 includes therein a CPU 1015, a RAM 1016, and a network interface 1017. A display 1018 and a keyboard 1019 for a user to operate the computer B 1003 are connected thereto at the outside thereof. Information stored in the RAM 1016 are as follows: A decryption processing program PROG3_1020, a random-number generation processing program PROG2_1021, and the secret key K 1011.

The computer A 1002 executes the encryption processing program PROG1_1009 so as to create a ciphertext C 1022 of the message M 1014, then transmitting the ciphertext C 1022 to the network 1001 via the network interface 1006. The computer B 1003, after receiving the ciphertext C 1022 via the network interface 1017, executes the decryption-processing program PROG3_1020. Then, if no forgery has been detected, the computer B 1003 stores the decrypted result into the RAM 1016.

The respective programs can be installed into the RAMs from the partner computers or another computer via a communications medium, i.e., the network 1001 or a carrier wave propagating on the network 1001, or via a transportable-type storage medium such as a CD or a FD. The respective programs can also be configured so that the programs will operate under (not-illustrated) operating systems of the respective computers. Also, each CPU reads out each program from each memory and executes each program, thereby implementing the processing by each program on each computer.

In the computer A 1002, the encryption processing program PROG1_1009 is read out from the RAM 1005, then being executed by the CPU 1004. The encryption-processing program PROG1_1009 calls up, as a subroutine, the random-number generation processing program PROG2_1010 in the inside, then outputting the ciphertext C 1022 to the inputted secret key K 1011 and the message M 1014.

In the computer B 1003, the decryption-processing program PROG3_1020 is read out from the RAM 1016, then being executed by the CPU 1015. The decryption-processing program PROG3_1020 calls up, as a subroutine, the random-number generation processing program PROG2_1021 in the inside, then outputting a message or a forgery -detection warning to the inputted secret key K 1011 and the ciphertext C 1022.

The explanation will be given below concerning the processing flow by the encryption-processing program PROG1_1009.

Step 2002: Data set subroutine. Inputting the secret key K is awaited.

Step 2003: Plaintext-preparation subroutine. Inputting the plaintext is awaited, and predetermined paddings are performed after the plaintext has been presented, and finally, the plaintext is separated on a 64-bit basis so as to output a string P_i ($1 \leq i \leq N$) of plaintext blocks. Here, N is assumed to be an even number.

Step 2004: Random-number generation subroutine. A pseudo random-number string R_i ($1 \leq i \leq N+1$) is outputted from the secret key K and the initial vector I.

Step 2005: Encryption subroutine. Ciphertext blocks C_i ($1 \leq i \leq N+2$) are outputted, using the pseudo random-number string R_i ($1 \leq i \leq N+1$) and the plaintext-block string P_i ($1 \leq i \leq N$).

Step 2006: The ciphertext blocks C_i ($1 \leq i \leq N+2$) acquired at the step 2005 are bit-connected in the sequence, then being outputted as the ciphertext C.

Referring to FIG. 2, the processing by the plaintext-preparation subroutine will be explained below.

Step 2202: Inputting the message M to be used for the cryptographic processing is awaited. The message M is inputted from the keyboard 1008, or has been stored in the RAM, or is introduced from another storage medium.

Step 2203: A padding is performed with data for indicating the length of the message M. Namely, 64-bit binary-number data for indicating the bit length of the message M is added to the front-end of the message M.

Step 2204: A padding for making the message length certain constant sizes. Namely, for the subsequent cryptographic processing, the message data after the padding is converted into an integral multiple of 128 bits. Concretely, assuming that the length of the message M is equal to L bits, the rear-end of the message to which the length data has been added at the step 2203 is padded with 0s which are equal to 128—(L(mod 128)) in number.

Step 2206: The message data is divided into the plaintext blocks. Namely, the message data acquired as the result of the step 2204 is separated into the 64-bit blocks, and the resultant blocks are specified as P_1, P_2, …, and P_N in the sequence.

Referring to FIG. 3, the processing by the random-number generation subroutine will be explained below.

Step 2302: The necessary parameters are inputted. Namely, the parameters acquired are the number N of the after-padding message blocks, the initial vector I, and the secret key K.

Step 2303: The pseudo random-number string R is generated. Namely, the random-number generation processing program PROG2 is called up, thereby generating the 64(N+1)-bit-length pseudo random-number string. This string then outputted is specified as R.

Step 2304: The pseudo random-number string R is divided into the blocks. Namely, the pseudo random-number string R is separated on a 64-bit basis, and the resultant pseudo random-number blocks are specified as R_1, R_2, …, and R_{N+1} in the sequence.

Referring to FIG. 4, the processing by the encryption and message-authentication-code generation set-up subroutine will be explained below.

Step 2403: A counter i is initialized. Namely, set i = 1.

Step 2404: The ciphertext blocks C_i are computed. Namely, set $C_i \leftarrow M_i$ EOR R_i.

Step 2406: If i = N, a step 2408 is executed.

Step 2407: The counter i is incremented, then returning back to the step 2404.

Step 2408: C_i $(1 \leq i \leq N)$ are bit-connected in the sequence, then being specified as S. R_i $(2 \leq i \leq N+1)$ are bit-connected in the sequence, then being specified as R.

Step 2409: An output from $NH_R(S)$ is separated on a 64-bit basis, and the resultant outputs are specified as C_{N+1} and C_{N+2}.

The explanation will be given later regarding the hash function $NH_R(S)$, referring to FIG. 11.

Referring to FIG. 5, the explanation will be given below concerning the processing flow by the decryption processing program PROG3_1020.

Step 2502: Data set subroutine. Inputting the secret key K is awaited.

Step 2503: Ciphertext-preparation subroutine.

Inputting the ciphertext C′ is awaited, and, after the ciphertext C′ has been presented, the ciphertext C′ is separated on a 64-bit basis so as to output a string C'_i ($1 \le i \le N+2$) of ciphertext blocks.

Step 2504: Random-number generation subroutine. The pseudo random-number string R_i ($1 \le i \le N+1$) is outputted from the secret key K.

Step 2505: C'_i ($1 \le i \le N$) are bit-connected in the sequence, then being specified as S. R_i ($2 \le i \le N+1$) are bit-connected in the sequence, then being specified as R. Next, $NH_R(S)$ is computed.

Step 2506: If $NH_R(S) = C'_{N+1} \| C'_{N+2}$, the processing proceeds to a step 2508. Otherwise, the processing proceeds to a step 2507.

Step 2507: A rejection (i.e., non-acceptance) is outputted. The processing proceeds to a step 2511.

Step 2508: Decryption subroutine. The string P'_i ($1 \le i \le N$) of the plaintext blocks is outputted, using the pseudo random-number string R_i ($1 \le i \le N$) and the ciphertext-block string C'_i ($1 \le i \le N$).

Step 2509: Plaintext cut-out subroutine. The string P'_i ($1 \le i \le N$) of the plaintext blocks is divided into data strings L′ and M′.

Step 2510: M′ is stored into the RAM.

At the step 2511, the decryption processing program outputs a result (i.e., the acceptance/non-acceptance or the decrypted result) to the display 1018, thereby informing the user of the result.

Referring to FIG. 6, the processing by the ciphertext-preparation subroutine will be explained below.

Step 2602: Inputting the ciphertext C′ is awaited.

Step 2603: The ciphertext C′ is separated on a 64-bit basis, and the resultant ciphertext blocks are specified as C'_1, C'_2, …, $C'_{N+1,}$ and C'_{N+2} in the sequence.

Referring to FIG. 7, the processing by the decryption subroutine will be explained below.

Step 2703: The counter i is initialized. Namely, set i = 1.

Step 2704: The plaintext blocks P'_i are computed. Namely, set $P'_i = C'_i \wedge R_i$.

Step 2706: If the case is not i = N, a step 2707 is executed.

Step 2707: The counter i is incremented, then returning back to the step 2704.

Referring to FIG. 8, the processing by the plaintext cut-out subroutine will be explained below.

Step 2802: L′ is set as the first 64-bit plaintext block (i.e., P'_1).

Step 2803: M′ is set as, of the decrypted-text blocks, the remaining L′-bit data which starts from the highest-order bit of P'_2.

FIG. 9 is an explanatory diagram of the encryption processing.

A length 2930 and a proper padding 2932 are each added to a message M 2931, thereby creating a plaintext P 2934.

This plaintext P 2934 is block-divided on a 64-bit basis, and the resultant plaintext blocks are specified as P_1_2935, P_2_2936, …, and P_N_2938, respectively.

An exclusive-OR logical sum of P_1_2935 with a random-number block R_1_2920 is figured out, thereby acquiring a ciphertext block C_1_2943.

An exclusive-OR logical sum of P_2_2936 with a random-number block R_2_2921 is figured out, thereby acquiring a ciphertext block C_2_2944.

These processings are similarly performed until P_N_2938, thereby acquiring the ciphertext blocks C_1_2943, C_2_2944, …, and C_N_2947. Next, $NH_R(S)$ is computed, selecting R and S as the inputs. Here, R results from connecting R_2_2921, R_3_2922, …, and R_{N+1}_2928 in this sequence, and S results from connecting C_1_2943, C_2_2944, …, and C_N_2947 in this sequence. Moreover, the computed output from $NH_R(S)$ is block-divided into C_{N+1}_2948 and C_{N+2}_2949. Furthermore, C_1_2943, C_2_2944, …, C_N_2947, C_{N+1}_2948, and C_{N+2}_2949 are connected in this sequence, thereby acquiring a ciphertext C_2956.

FIG. 10 is an explanatory diagram of the decryption processing.

A ciphertext C'_4030 is divided into 64-bit blocks, and the resultant ciphertext blocks are specified as C'_1_4035, C'_2_4036, …, C'_N_4037, C'_{N+1}_4038, and C'_{N+2}_4039. Next, $NH_R(S)$ is computed, selecting R and S as the inputs. Here, R results from connecting R_2_4021, R_3_4022, …, and R_{N+1}_4028 in this sequence, and S results from connecting C'_1_4035, C'_2_4036, …, and C'_N_4037 in this sequence. If $NH_R(S) = C'_{N+1}$_4038 $\|$ C'_{N+2}_4039, the processing proceeds to the next step.

An exclusive-OR logical sum of C'_1_4035 with R_1_4020 is figured out, thereby acquiring a plaintext block P'_1_4043.

An exclusive-OR logical sum of C'_2_4036 with R_2_4021 is figured out, thereby acquiring a plaintext block P'_2_4044.

These processings are similarly performed until C'_N_4037, thereby acquiring the plaintext blocks P'_1_4043, P'_2_4044, …, and P'_N_4047. After that, these blocks are connected in this sequence, then being specified as a plaintext P'_4050. This plaintext P'_4050 is divided into L'_4051 and M'_4052.

Referring to FIG. 11, the explanation will be given below regarding the hash function $NH_R(S)$ addressed in the document 2.

Selecting the message M and the key K as the inputs, this function generates and outputs the message authentication code C. This message-authentication-code generation is executed as follows: Also, in the following algorithm, an arrow ← and a notation $\|$ denote data substitution and data connection, respectively. Firstly, assume that $M = M_1 \| \ldots \| M_N$ and $K = K_1 \| \ldots \| K_N$.

$H_i \leftarrow M_i + K_i \ (1 \leq i \leq N)$

$S_i \leftarrow H_{2i-1} \times H_{2i} \ (1 \leq i \leq N/2)$

$C \leftarrow S_1 + S_2 + \ldots + S_{N/2}$

Finally, the message authentication code C is outputted.

In the first embodiment, the pseudo random numbers are necessary for the two processings, i.e., the cryptographic processing and the message-authentication-code generation. Here, the length of the pseudo random numbers is satisfying enough if it is substantially the same as that of the message.

Also, on a computer where a general-purpose CPU is employed, the pseudo random-number generator according to the present embodiment allows the implementation of the random-number generation processings which are more than 2 times higher as compared with the ones by AES, i.e., the highest cipher among the block ciphers. Consequently, the present embodiment allows the implementation of the processings which, on one and the same environment, are more than 2 times higher as compared with the iaPCBC mode which is the conventional technology. (Second Embodiment) Hereinafter, the explanation will be given below concerning the second embodiment of the present invention. The second embodiment, basically, is the same as the first one, and thus only the modified points will be explained below.

The explanation will be given below regarding the processing flow by the encryption processing program PROG1_1009.

Step 5002: Data set subroutine. Inputting the secret key K is awaited.

Step 5003: Plaintext-preparation subroutine. Inputting the plaintext is awaited, and predetermined paddings are performed after the plaintext has been presented, and finally, the plaintext is separated on a 64-bit basis so as to output a string P_i ($1 \le i \le N$) of plaintext blocks. Here, N is assumed to be an even number.

Step 5004: Random-number generation subroutine. A 64(3N/2+1)-bit pseudo random-number string is outputted from the secret key K and the initial vector I.

Step 5005: Encryption subroutine. Ciphertext blocks C_i ($1 \le i \le N+2$) are outputted, using the pseudo random-number string acquired at the step 5004 and the plaintext-block string P_i ($1 \le i \le N$).

Step 5006: The ciphertext blocks C_i ($1 \le i \le N+2$) acquired at the step 5005 are bit-connected in the sequence, then being outputted as the ciphertext C.

Referring to FIG. 12, the processing by the random-number generation subroutine will be explained below.

Step 5302: The necessary parameters are inputted. Namely, the parameters acquired are the number N of the after-padding message blocks, the initial vector I, and the secret key K.

Step 5303: The pseudo random-number string R is generated. Namely, the random-number generation processing program PROG2 is called up, thereby generating the 64(3N/2+1)-bit pseudo random-number string R.

Step 5304: The pseudo random-number string R is divided into the blocks. Namely, the pseudo random-number string R is separated on a 64-bit basis, and the resultant blocks are specified as R_1, R_2, ..., R_{N+1}, ..., and $R_{3N/2+1}$ in the sequence.

Step 5305: R_{N+1}, ..., and $R_{3N/2}$ are connected in this sequence, then being specified as R'.

Step 5306: R_{N+2}, ..., and $R_{3N/2+1}$ are connected in this sequence, then being specified as R''.

Referring to FIG. 13, the processing by the encryption and message-authentication-code generation set-up subroutine will be explained below.

Step 5403: A counter i is initialized. Namely, set i = 1.

Step 5404: The ciphertext blocks C_i are computed. Namely, set $C_i \leftarrow M_i$ EOR R_i.

Step 5405: If i = N, a step 5407 is executed.

Step 5406: The counter i is incremented, then returning back to the step 5404.

Step 5407: The counter i is initialized. Namely, set i = 1.

Step 5408: C_i are separated on a 32-bit basis, and the resultant blocks are specified as $C_{i,H}$ and $C_{i,L}$.

Step 5409: If i = N/2, a step 5411 is executed.

Step 5410: The counter i is incremented, then returning back to the step 5408.

Step 5411: $C_{1, H,}$ $C_{1, L}$, …, $C_{N/2, H,}$ and $C_{N/2, L}$ are bit-connected in the sequence, then being specified as S.

Step 5412: An output from $NH_{R'}(S)$ is specified as C_{N+1}.

Step 5413: An output from $NH_{R''}(S)$ is specified as C_{N+2}.

Referring to FIG. 14, the explanation will be given below regarding the processing flow by the decryption-processing program PROG3_1020.

Step 5502: Data set subroutine. Inputting the secret key K is awaited.

Step 5503: Ciphertext-preparation subroutine. Inputting the ciphertext C′ is awaited, and, after the ciphertext C′ has been presented, the ciphertext C′ is separated on a 64-bit basis so as to output a string C'_i ($1 \leq i \leq N+2$) of ciphertext blocks.

Step 5504: Random-number generation subroutine. The pseudo random-number string R_i ($1 \leq i \leq 3N/2+1$), R′, and R″ are outputted from the secret key K.

Step 5505: C'_i ($1 \leq i \leq N$) are bit-connected in the sequence, then being specified as S. Next, $NH_{R'}(S)$ and $NH_{R''}(S)$ are computed.

Step 5506: If $NH_{R'}(S) = C'_{N+1}$ and $NH_{R''}(S) = C'_{N+2}$, the processing proceeds to a step 5508. Otherwise, the processing proceeds to a step 5507.

Step 5507: A rejection (i.e., non-acceptance) is outputted. The processing proceeds to a step 5511.

Step 5508: Decryption subroutine. The string P'_i ($1 \le i \le N$) of the plaintext blocks is outputted, using the pseudo random-number string R_i ($1 \le i \le N$) and the ciphertext-block string C'_i ($1 \le i \le N$).

Step 5509: Plaintext cut-out subroutine. The string P'_i of the plaintext blocks is divided into data strings L' and M'.

Step 5510: M' is stored into the RAM.

At the step 5511, the decryption processing program outputs a result (i.e., the acceptance/non-acceptance or the decrypted result) to the display 1018, thereby informing the user of the result.

FIG. 15 is an explanatory diagram of the encryption processing.

A length 5930 and a proper padding 5932 are each added to a message M 5931, thereby creating a plaintext P 5934. This plaintext P 5934 is block-divided on a 64-bit basis, and the resultant plaintext blocks are specified as P_1_5935, P_2_5936, $P_{N/2}$_5937, ..., and P_N_5938, respectively. An exclusive-OR logical sum of P_1_5935 with R_1_5920 is figured out, thereby acquiring a ciphertext block C_1_5943. An exclusive-OR logical sum of P_2_5936 with R_2_5921 is figured out, thereby acquiring a ciphertext block C_2_5944.

These processings are similarly performed until P_N_5938, thereby acquiring the ciphertext blocks C_1_5943, C_2_5944, ..., and C_N_5947. Next, $NH_{R'}(S)$ is computed, selecting S as the input. Here, S results from connecting C_1_5943, C_2_5944, ..., and $C_{N/2}$_5945 in this sequence. Moreover, the computed output from $NH_{R'}(S)$ is specified as C_{N+1}_5948,

$NH_{R''}(S)$ is computed, and the output therefrom is specified as C_{N+2}_5949. C_1_5943, C_2_5944, ..., $C_{N/2}$_5945, ..., C_N_5947, C_{N+1}_5948, and C_{N+2}_5949 are connected in this sequence, thereby acquiring a ciphertext C_5956.

FIG. 16 is an explanatory diagram of the decryption processing.

A ciphertext C'_6030 is divided into 64-bit blocks, and the resultant blocks are specified as C'_1_6033, C'_2_6034, ..., C'_N_6037, C'_{N+1}_6038, and C'_{N+2}_6039. Next, $NH_R(S)$ is computed, selecting S as the input. Here, S results from connecting C'_1_6033, C'_2_6034, $C'_{N/2}$_6035, ..., and C'_N_6037 in this sequence. If $NH_{R'}(S)$ = C'_{N+1}_6038 and $NH_{R''}(S)$ = C'_{N+2}_6039, the processing proceeds to the next step.

An exclusive-OR logical sum of C'_1_6033 with R_1_6020 is figured out, thereby acquiring a plaintext block P'_1_6043. An exclusive-OR logical sum of C'_2_6034 with R_2_6031 is figured out, thereby acquiring a plaintext block P'_2_6044.

These processings are similarly performed until C'_N_6037, thereby acquiring the plaintext blocks P'_1_6043, P'_2_6044, ..., and P'_N_6047. After that, these blocks are connected in this sequence, then being specified as a plaintext P'_6050. This plaintext P'_6050 is divided into L'_6051 and M'_6052.

In the second embodiment, the pseudo random numbers are necessary for the two processings, i.e., the cryptographic processing and the message-authentication-code generation. Here, the length of the pseudo random numbers is substantially 1.5 times longer than that of the message. Also, on a computer where a general-purpose CPU is employed, the pseudo random-number generator according to the present embodiment allows the implementation of the random-number generation processings which are more than 2 times higher as compared with the ones by AES, i.e., the highest cipher among the block ciphers. From the consideration given above, the method according to the second embodiment allows the implementation of the processings which, on one and the same environment, are more than 4/3 times higher as compared with the iaPCBC mode which is the conventional technology.

Also, a theorem 2 in the document 2 where $w = 32$ and $t = 2$ are set is applied to the second embodiment. This makes it possible to accomplish the security proof. Namely, with respect to two different messages whose lengths are equal to each other, the provability that their message authentication codes become identical is equal to 2^{-64}.

The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. It will, however, be evident that various modifications and changes may be made thereto without departing from the spirit and scope of the invention as set forth in the claims.